MTL-TR 87-50

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HYDROGEN INDUCED CRACKS IN ARMOR STEEL WELDMENTS FABRICATED WITH AUSTENITIC FILLER ALLOYS

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PROCESSING TECHNOLOGY DIVISION

September 1987

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: MTL TR 87-50	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): HYDROGEN INDUCED CRACKS IN ARMOR STEEL WELDMENTS FABRICATED WITH AUSTENITIC FILLER ALLOYS	5. TYPE OF REPORT & PERIOD COVERED: Final Report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): William S. Ricci	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Materials Technology Laboratory, Watertown, Massachusetts 02172-0001, SLCMT-MCD	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: D/A Project: 1L263102D077; Agency Accession: DA 30 3398
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Army Laboratory Command, 2800 Powder Mill Road, Adelphi, Maryland 20783-1145	12. REPORT DATE: September 1987
	13. NUMBER OF PAGES: 11
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Welding, Armor, Stainless steel, Hydrogen, Cracking

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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ABSTRACT

Hydrogen induced cracks have been identified in the weld metal of cast armor steel weldments fabricated with austenitic electrodes. Cracks propagated through a well defined band of martensite located between the fusion boundary and the composite region of the weld metal. Martensite band formation was found to result from the combined effects of vigorous hydrodynamic forces, especially in large molten weld pools, and the interdiffusion of alloying elements in that system formed between the base metal and the weld metal. Methods of controlling this form of cracking include limiting base metal dilution, minimizing the concentration of available hydrogen in the welding arc atmosphere, or the selection of more suitable ferritic filler alloys.

(Keywords: -

BACKGROUND

The work reported here was performed as part of a failure analysis of M60 tank tow lug weldments and was sponsored by the Program Manager-M60 tanks.

INTRODUCTION

Austenitic filler materials are often used to join high hardenability armor steels. The main reason for their selection over ferritic filler alloys has traditionally been that they provide a deterrent to hydrogen induced cracking (HIC) in applications where preheat or post weld heat treatment would be impractical or cost prohibitive or when excessive arc atmosphere contamination would be unavoidable. Examples of such applications include the field repair or appurtenance welding of thick walled ballistic structures.

Austenitic weld metals have a higher solubility for hydrogen than ferritic weld metals or heat affected zones (HAZs). Hydrogen in crack sensitive martensitic HAZs is, therefore, able to escape at a faster rate than it is replenished by hydrogen from austenitic weld deposits. This results in a lower hydrogen concentration in martensitic HAZs, and this reduces the tendency to initiate HIC.

The lower yield strengths of austenitic filler alloys is also believed to contribute to their reduced tendency to form hydrogen induced cracks. This is mainly due to the relief of HAZ residual stresses that result from localized plastic deformation in the weld metal.[1,2]

Typically, cracks in armor weldments fabricated with austenitic electrodes are found in the weld metal oriented transverse to the weld axis. Similarly, hydrogen induced cracks in armor weldments fabricated with ferritic filler materials are typically found in the HAZ parallel to the weld axis, Figure 1.[*] Cracks in armor weldments fabricated with austenitic electrodes, located in the weld metal but oriented parallel to the weld axis and away from the weld centerline, have not, however, been previously documented.

The occurrence of hydrogen induced cracks in the intermediate zone of armor steel weldments fabricated with austenitic electrodes will be discussed in this report. The term "intermediate zone" refers to parts of the composite region of the weld as well as the partially melted zone, the unmixed zone, and the weld interface, as defined by Baeslack et al.[3] (Figure 2).

EXPERIMENTAL

Shielded metal arc welded appurtenances, fabricated with type 307 austenitic stainless steel electrodes, were removed from M60 tank hulls. The chemical compositions of the weld metal and base metal are shown in Table 1. The composition of the base metal was consistent with that of cast armor steel (MIL-A-11356).

[*]RICCI, W.S. Unpublished research, 1983.

1. CASTRO, R., and de CADENET, J.J. *Welding Metallurgy of Stainless and Heat Resisting Steels* Cambridge University Press, Great Britain, 1975.
2. *Effective Use of Weld Metal Yield Strength for HY Steels.* Committee on Effective Utilization of Weld Metal Yield Strength, NMAB Report No. 380, January 1983.
3. BAESLACK, W.A., LIPPOLD, T.C., and SAVAGE, W.F. *Unmixed Zone Formation in Austenitic Stainless Steel Weldments.* Welding Journal, v. 58, no. 6, June 1979.

Table 1. CHEMICAL COMPOSITIONS OF WELD METAL AND BASE METAL

	C	Mn	Si	Cr	Ni	Mo	S	P
Weld Metal	0.1	3.9	0.4	20.0	9.5	0.9	0.03	0.026
Base Metal	0.25	1.16	0.53	1.02	1.01	0.42	0.019	0.016

All welds were inspected for cracks by visual and liquid penetrant techniques. Cracks were sectioned and prepared for metallographic examination. A 50% glycerine, 30% hydrochloric acid, 20% nitric acid etchant was used to define both weld metal and HAZ microstructures. Hardness traverses were taken from polished and etched specimens. Fracture surfaces were examined in an SEM.

RESULTS

Metallography revealed cracks located in the weld metal adjacent to the fusion boundary on both sides of welded joints. Figure 3 shows one such crack. All cracks propagated through a continuous band of martensite at or adjacent to the fusion boundary (Figures 4 and 5). This martensite band ranged in width from 10-140 μm, and in some locations was completely divorced from the fusion boundary by a thin layer of austenitic weld metal (Figure 5). No cracks were found in areas where this band was discontinuous or nonexistent (Figures 6 and 7).

A hardness traverse was taken across weld fusion boundaries. Knoop hardness data were taken through the weld metal, the fusion boundary, the HAZ, and into the unaffected base metal. This data is presented in Figure 8. The martensitic phase through which the cracks propagated had a hardness of approximately 420 KHN, which is significantly higher than that of the weld metal (225 KHN), HAZ (320 KHN) and unaffected base metal (280 KHN).

SEM examination of the fractured surface revealed a mixed mode, intergranular-transgranular fracture path. This is characteristic of hydrogen induced cracks that propagate at low stress intensity levels.

DISCUSSION

The hydrogen induced cracks observed resulted from the presence of a susceptible microstructure (i.e., martensite) in a "hydrogen charged reservoir" (austenite). This cracking phenomenon has not been widely documented in the open literature.

Several investigators[4,5] have studied the formation of martensite at the weld fusion boundary. This martensite formation is believed to be due to the interdiffusion of alloying elements in that system between the base metal and the weld metal. Kinetics alone, however, fall short of explaining martensite formations in bands adjacent to, but divorced from, the fusion boundary (Figure 5). Figure 9 shows an example of a martensite band extending a relatively large distance into the weld metal along the fusion boundary of successive weld passes. A more complete

4. ORNATH, F., SOUNDRY, J., WEISS, B.Z., and MINKOFF, I. *Weld Pool Segregation During the Welding of Low Alloy Steels With Austenitic Electrodes.* Welding Journal, v. 60, no. 11, November 1981.
5. LANCASTER, J.F. *Metallurgy of Welding.* George Allen and Unwin, London, 1980.

explanation for the observed martensite band formation is that, in addition to kinetics, hydrodynamic forces play a major role. These forces are sufficient, especially in large molten weld pools, to physically wash away part of the fusion zone and introduce it into the composite region of the weld metal.

The Schaeffler diagram (Figure 10) can provide a first approximation of the effect of base metal dilution on martensite formation. For the alloy systems of interest here, only 17% dilution of the filler alloy with the base metal will result in the formation of martensite. It should be recognized that 40% dilution is often encountered under ordinary welding conditions, especially in the root pass. One alternative in resolving this problem, therefore, would be the use of higher alloy filler metals such as 309, 310 or 312 that can tolerate more dilution because of their more stable duplex austenite-ferrite structure. For example, 312 weld metals can tolerate approximately 45% dilution without forming martensite. The use of these alloys in other than high dilution passes (such as the root and buttering passes) is not recommended, however, since high ferrite contents reduce the ductility of the duplex structure.

The elimination of martensite is not the only method of deterring HIC in austenitic weld deposits. It is often more economical to reduce HIC susceptibility by reducing the available hydrogen concentration in the welding arc. This reduction can usually be attained by using electrodes with low moisture contents, and is generally considered to be the preferred alternative.

CONCLUSIONS

1. Hydrogen induced cracks have been identified in armor steel weldments fabricated with austenitic electrodes.

2. Hydrogen induced cracks may form in a well defined band of martensite located between the fusion boundary and the composite region of the weld metal.

3. Martensite band formation is due to the combined effects of vigorous hydrodynamic forces, especially in large molten weld pools, and the interdiffusion of alloying elements in that system formed between the base metal and the weld metal.

4. Cracking can be effectively controlled by limiting base metal dilution and minimizing the concentration of available hydrogen in the welding arc.

5. The use of higher alloy filler materials is recommended for critical applications, especially in the root pass.

6. More economical ferritic filler alloys should be used whenever low hydrogen conditions can be properly maintained.

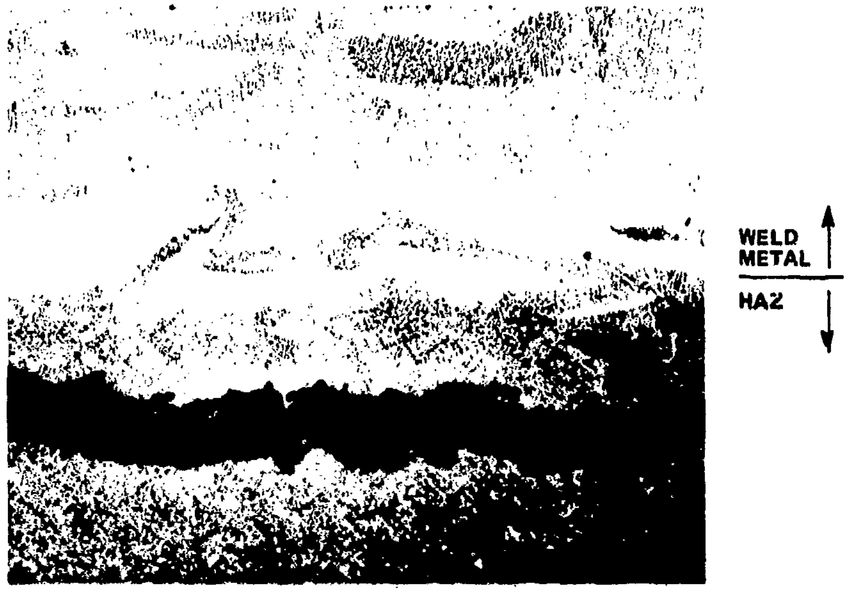

Figure 1. Hydrogen induced crack located in the HAZ of an armor steel weldment (150X).

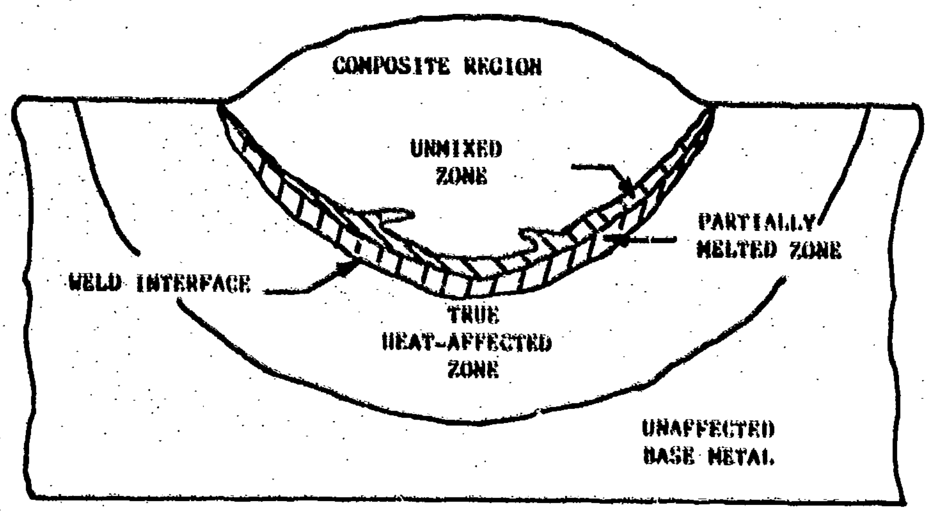

Figure 2. Schematic illustration showing the regions of a heterogeneous weld.

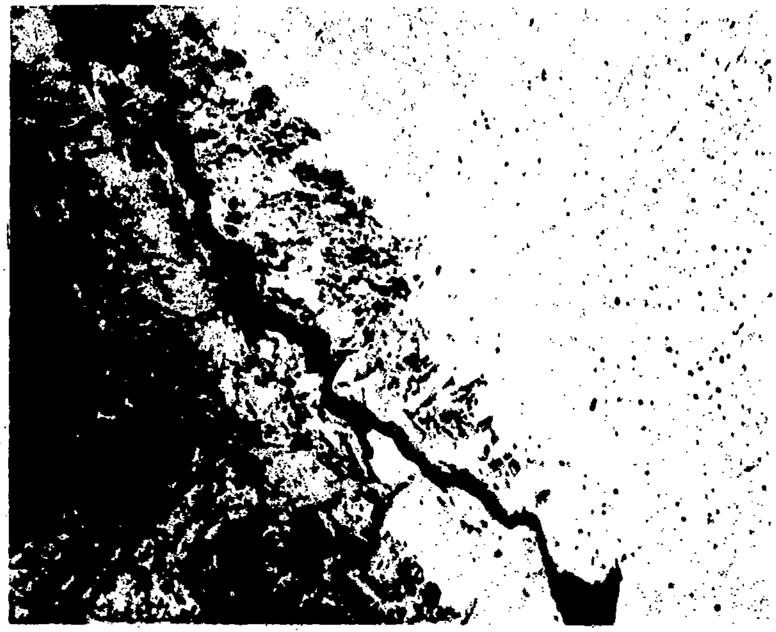

Figure 3. Crack in weld metal adjacent to fusion boundary (37.5X).

Figure 4. Crack propagating through a continuous band of martensite in weld metal along fusion boundary (375X). Crack deviation was due to multipass welding conditions.

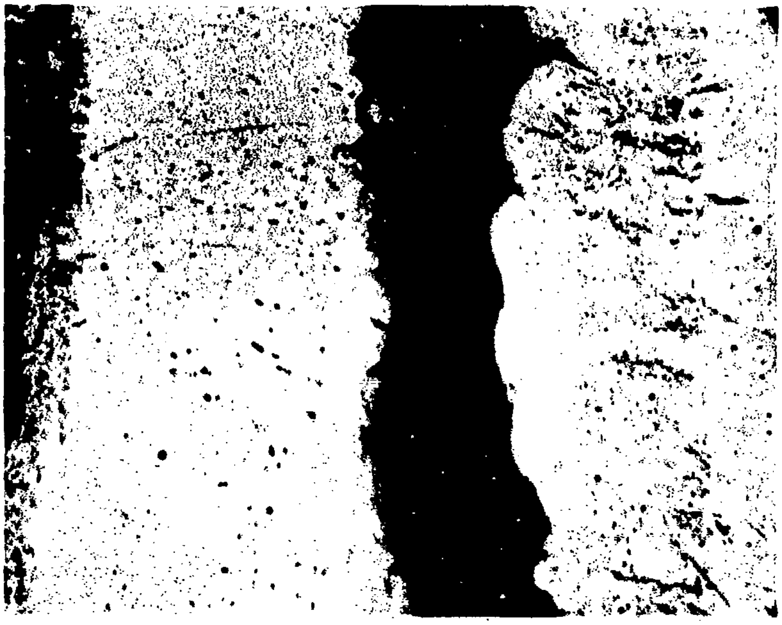

Figure 5. Crack in martensite band separated from fusion boundary by a thin layer of austenite (375X).

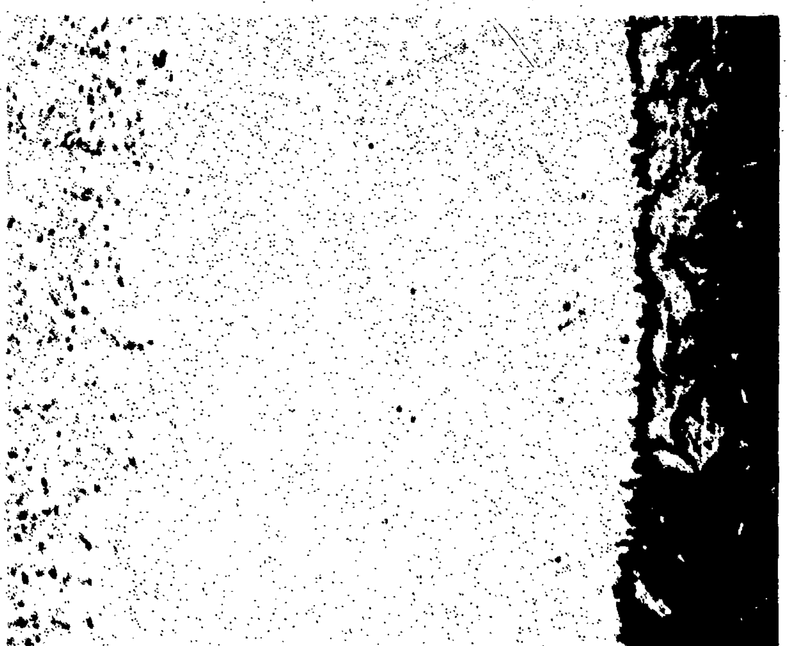

Figure 6. Discontinuous band of martensite adjacent to the fusion boundary (375X).

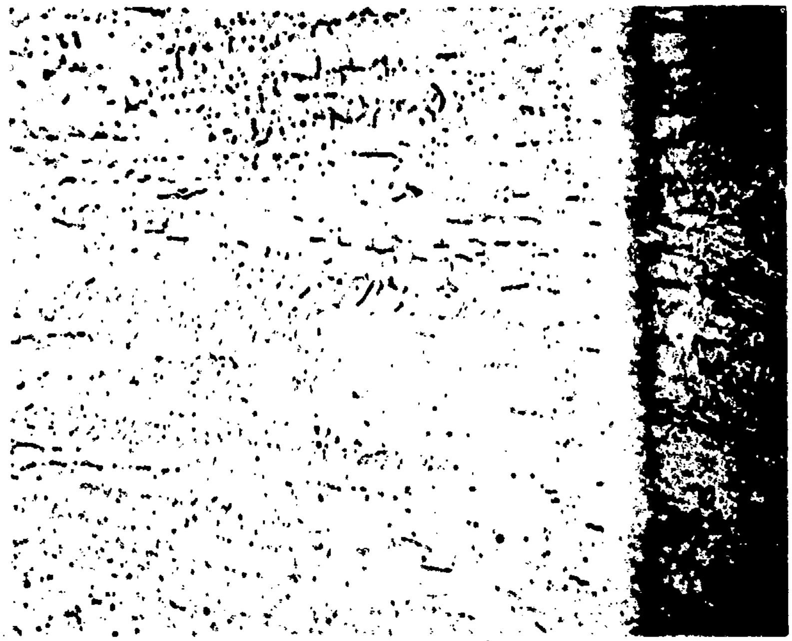

Figure 7. Reduced levels of dilution resulted in martensite-free fusion boundaries (375X).

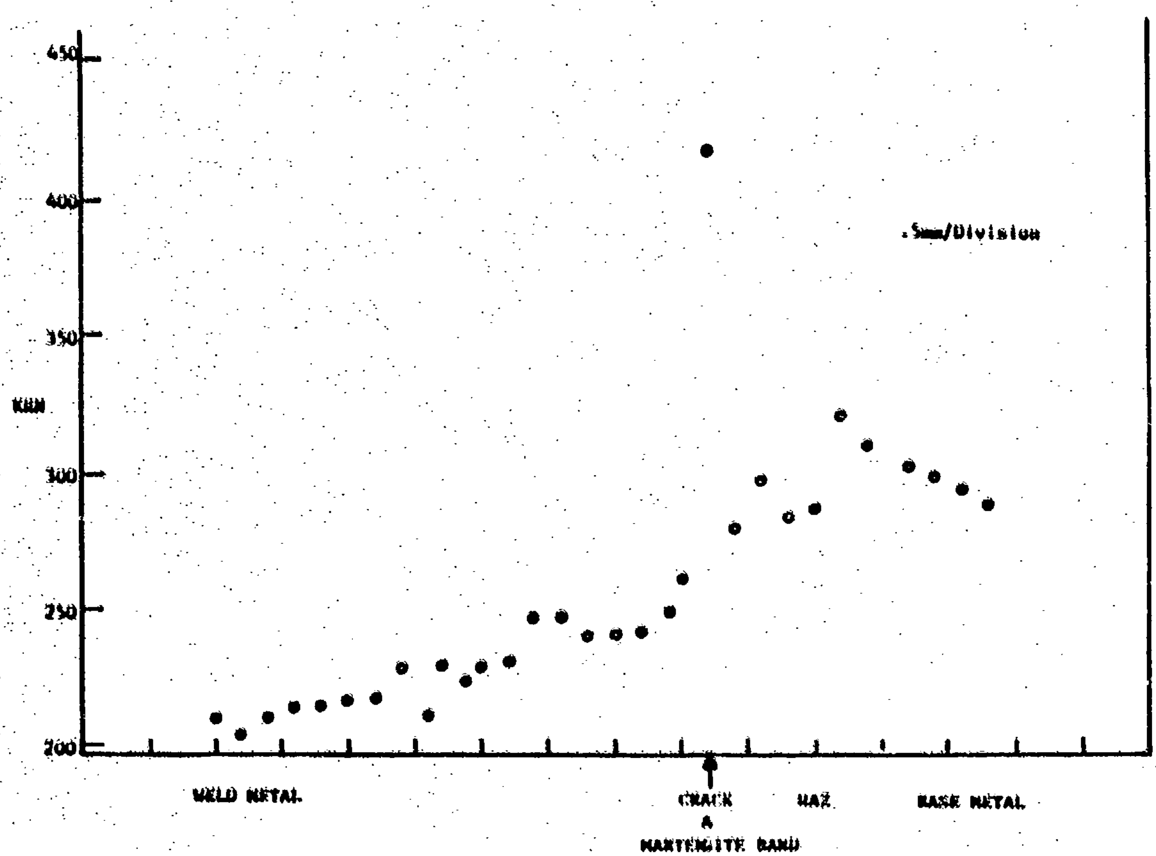

Figure 8. Hardness traverse taken across the weld fusion boundary.

Figure 9. Martensite band extending along fusion boundary of successive weld passes (37.5X).

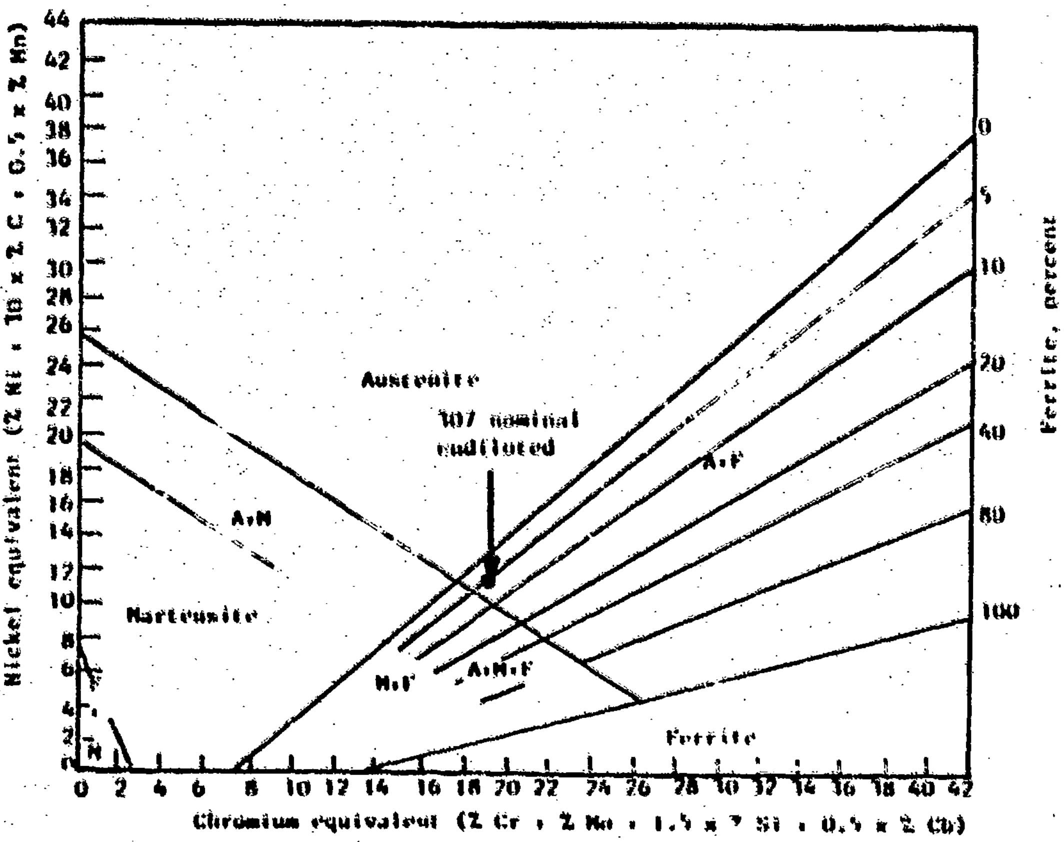

Figure 10. Schaeffler diagram for estimating the microstructure of stainless steel weld metal.

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